

Design Of A Dual Moving-Magnet Motor For A Hard Disk Drive Actuator

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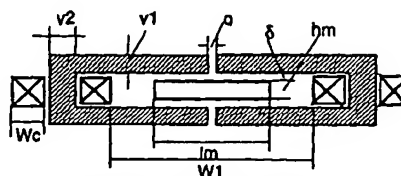
Abstract - This paper presents the design and the measured performance of a moving-magnet motor intended to drive a high bandwidth actuator assembly. The motor includes two magnets which are arranged to provide mainly torque rather than force. As a reference point, measurements are also made on a conventional moving coil actuator from a commercial 3.5" hard disk drive. The dual moving-magnet actuator is found to have better electromechanical characteristics and to be more power effective than the reference actuator.

I. INTRODUCTION

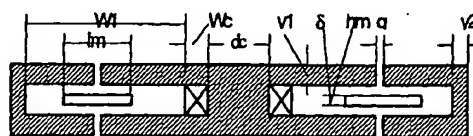
High track-density magnetic recording can be achieved by using a good track following servo and an actuator with improved electromechanical dynamics. There are several approaches to improving the electromechanical dynamics of the actuator: the two-actuator approach - one conventional moving coil actuator with a secondary mini- or micro-actuator mounted on the arm; and the one-actuator approach - an orthogonal force or pure torque actuator with a high bandwidth structure [1]. The latter is more favorable for its reliability and cost effectiveness. This paper presents the design and the measured performance of a moving-magnet motor intended to drive a high bandwidth actuator assembly [2]. The motor includes two magnets which are arranged to provide mainly torque rather than force. As a reference point, measurements are also made on a conventional moving coil actuator from a commercial 3.5" hard disk drive. The dual moving-magnet actuator is found to have better electromechanical characteristics and to be more power effective than the reference actuator.

II. MOTOR CONFIGURATIONS

A number of moving magnet motors were designed and analyzed using the finite element method. Each configuration has its pros and cons. The following two configurations are found to be more power effective and lower cost. The first, having a single moving magnet and two stationary coils, can be an alternative to the conventional moving coil actuator. The second, having two moving magnet and a stationary coil, can form a 'butterfly' configuration and provide mainly torque.



(a) Single moving-magnet motor



(b) Dual Moving-Magnet motor

Fig.1 Moving magnet motor configurations

III. ANALYSIS AND OPTIMIZATION

The designs of the single moving magnet actuator, SMA and the dual moving magnet actuator, DMA, were optimized using a 2-D finite element analysis to maximize the motoring force and minimize the bias force. The following parameters were adjusted for this purpose: (1) tilt angle, α , of the inner surface of the top/bottom yokes; (2) magnetic materials; (3) air gap lengths, g and δ ; and (4) thickness of yokes, $y1$ and $y2$.

It is seen that from Table I that reducing the air-gap g may lead to a small bias force. But the motoring force may be reduced also because of less interaction between magnet and excitation current. The bias force can be significantly reduced by slanting the inner surface of the top and bottom yokes. It is seen that the bias force is reduced from 225.78 N/m to 3.37 N/m by a slant of 3.37° . The bias force is very sensitive to the slanting angle. It is too difficult to control the machining tolerance and achieve designed performance. Therefore the most critical parameters in the optimization are the thickness of yoke and its magnetic properties because the bias force is actually caused by the nonlinearity of the yoke material.

Several designs of the dual moving magnet motor are given in Table III. The bias force profile after optimization is given in Fig.3. After optimization, the bias force is reduced to a negligible level. Fig.4 shows the flux line plot of the DMA motor at the end stroke position under different currents.

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Table I: SMA Bias force as function of the air-gap g

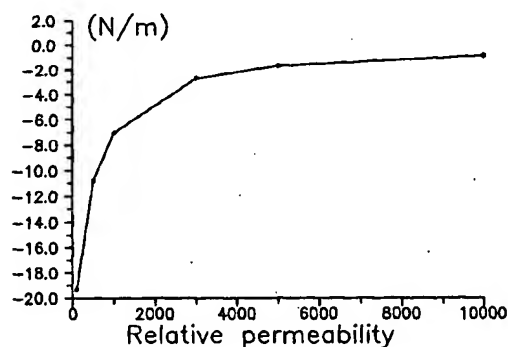
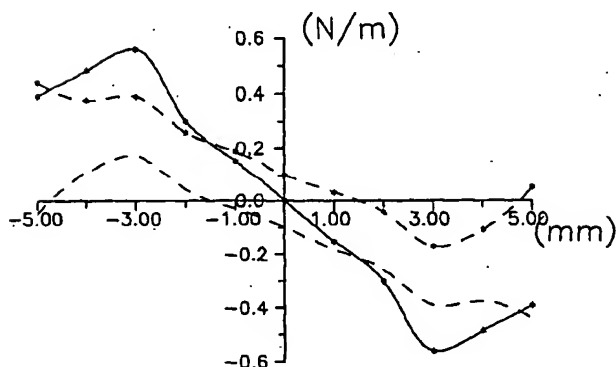
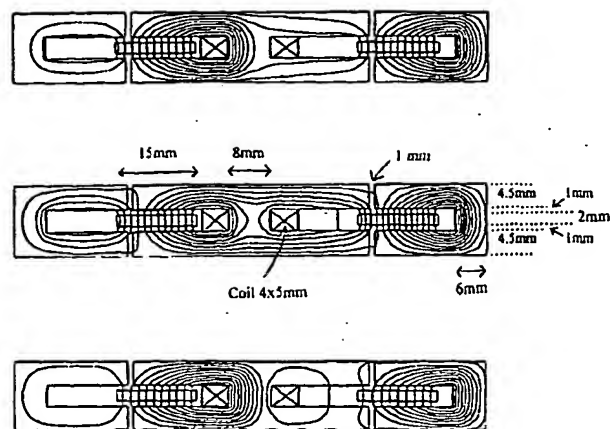
	$g = 1.0 \text{ mm}$	$g = 0.33 \text{ mm}$
Bias force (N/m)		
$\alpha = 0.0$, $y_1 = 3 \text{ mm}$, $y_2 = 4 \text{ mm}$, $X_m = 5 \text{ mm}$	-225.78	-137 N/m

Table II: SMA Bias force as function of the surface slanting angle α

	$\alpha = 0.0$	$\alpha = 1.68^\circ$	$\alpha = 3.37^\circ$
Bias force (N/m)			
$g = 1 \text{ mm}$, $y_1 = 3 \text{ mm}$, $y_2 = 4 \text{ mm}$, $X_m = 5 \text{ mm}$	-225.78	-92	3.37

Table III: Actuator Force as function of the steel yoke thickness and the air-gap δ

	case-1	case-2	case-3
y_1 (mm)	5.0	4.5	6.0
y_2 (mm)	4.0	6.0	6.0
g (mm)	1.0	1.0	1
δ (mm)	0.5	1.0	0.5
Actuator Height (mm)	13.0	13.0	15.0
bias force (N/m)	-33.0	-0.39	-1.873
X_m	5.0	5.0	5.0
Actuator Force (N/m)			-245.8
($I = \pm 180 \text{ A}$)			/218.0
Actuator Force (N/m)		-242.4	
($I = \pm 240 \text{ A}$)		/211.5	

Fig.2 Bias force as a function of the relative permeability of the steel yoke ($g=1.0 \text{ mm}$, $a = 0.0$, $y_1=3 \text{ mm}$, $y_2=4 \text{ mm}$)Fig.3 Bias force of DMA motor, as a function of the magnet position
Dashed line: Bias force on the magnet in the left
Dashed line with dots: Bias force on the magnet in the right
Solid line: The resultant bias force of the actuatorFig.4 Flux line plot of DMA motor at end stroke position
top : zero current, middle: 240 Amp.turn
bottom : -240 Amp.turn

IV. MEASUREMENT RESULTS OF DMA MOTOR PROTOTYPE

The dual moving magnet motor is implemented as shown in Fig.5. It has the same overall height as the reference actuator, a commercially available actuator for 3.5" hard disk drives. The two 1.5mm-thick sintered NdFeB magnets are identical to those in the reference actuator. The moving magnet structure is stiffer than the moving coil and the resonant frequency of the motor structure is expected to be higher. The yoke is made of mild steel. The stationary coil has an inductance of 30.4 mH and a resistance of only 25.2 ohms at the frequency of 40Hz. It is a simple circular solenoid with 445 turns of 0.14 mm diameter wire. The copper utilization factor is 1.0, compared with 0.6 for a conventional moving coil actuator.

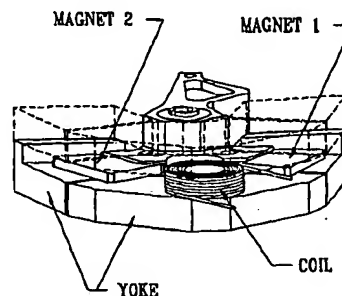


Fig.5 The prototype of the dual moving magnet motor

Measurements were made on two of the dual moving magnet motors having un-annealed and annealed yokes,

respectively. The measured torque constant for the motor with annealed yokes is 0.1157, 1.29 times as large as the motor with un-annealed yokes. The saturation flux density is much increased and the bias force is much reduced after the yokes were annealed. The bias current that cancels the bias magnetic force as shown in Fig.6 exhibits hysteresis due to the poor magnetic properties of the yoke steel. It can be minimized using better magnetic steel.

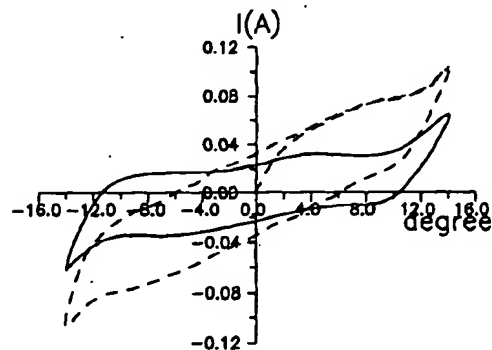


Fig.6 Measured bias current that cancels the bias magnetic force
solid line : yoke annealed; dashed line: yoke not annealed

The force was measured on the arm tip about 35mm from the pivot. The torque was then calculated from the force measured and the arm length. The solid line in Fig.7 is the torque measured at the middle position. The results measured from both sides of the tip, i.e., two opposite directions, are almost the same, showing good consistency and repeatability. The dashed line is the torque measured at the extreme stroke positions, which, again, is almost the same for both of the extreme stroke end. The difference shown between the two lines is due to the bias force. The slope of these lines is the torque constant.

The motor constant for the dual moving magnet actuator is 0.02485 (Nm/W^{0.5}), a factor of 1.23 higher than that of the reference actuator. However, the moving magnet actuator does exhibit a relatively high bias force of 0.159 N(bias torque 3.5 Nmm).

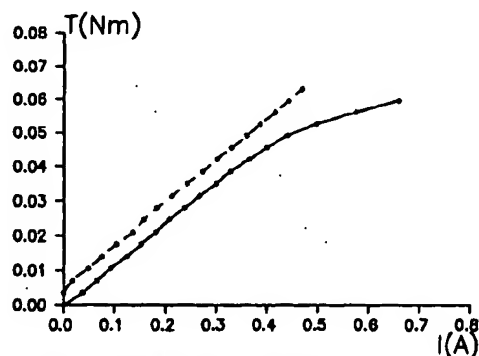


Fig. 7 Torque as functions of applied current
solid line: middle positions
dashed line: stroke end position

Measurements were also made on the reference actuator. A comparison of their characteristics is given as follows

Table IV. Performance comparison

	DMA Motor 1	DMA Motor 2	Reference Actuator
number of turns	445	445	
Yoke properties	not annealed	Annealed	
τ_m (ms)	15.67	8.95	13.9
τ_e (ms)	0.19	0.204	0.174
$\tau_e \tau_m$ (ms) ²	2.966	1.826	2.418
K_m (Nm/W ^{0.5})	0.01878	0.02485	0.02022
a_s	3390.5	4495.0	3352.1

In Table IV, τ_m is the mechanical constant, τ_e the electrical constant, K_m the motor constant and a_s the specific acceleration.

It is seen that, the motor constant for the dual moving magnet actuator is 0.02485 (Nm/W^{0.5}), a factor of 1.23 higher than that of the reference actuator. The dual moving magnet actuator is more efficient than the reference actuator. However, the moving magnet actuator does exhibit a relatively high bias force of 0.159 N(bias torque 3.5 Nmm). And eddy current in the yoke is found to play a critical role in adding phase-lag, reducing torque at high frequencies, and reducing the suppression of the lateral force. The eddy current problem will be solved using a laminated yoke, and the dynamic performance of the actuator will be comparable to the reference actuator.

CONCLUSION

A prototype dual moving-magnet motor has been applied in an actuator for a hard disk drive. In some respects the motor has much better electromechanical characteristics than a conventional moving coil design. However some concerns remain regarding hysteresis and bias forces and several effects related to the presence of eddy-currents in the yoke.

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